Study into the Effect of Crude Palm Oil (CPO) as a Cutting Fluid on Surface Finish during Milling.

by

Hairani Sudin

Dissertation submitted in partial fulfillment of

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BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(Hairani Sudin)

ABSTRACT

Lubricants are being utilized in all sectors of industry for lubricating their machines and materials. Reports indicate that nearly 38 million metric tons of lubricants were used globally in 2005, with a projected increase of 1.2% over the next decade. Approximately 85% of lubricants being used around the world are petroleum-based oils. Enormous use of petroleum based oils, created many negative effects on environment. The major negative effect is particularly linked to their inappropriate use, which results in surface water and groundwater contamination, air pollution, soil contamination, and consequently, agricultural product and food contamination.

To overcome these challenges, scientists and tribologists are currently exploring various alternatives to petroleum-based MWFs. Such alternatives include synthetic lubricants, solid lubricants and vegetable-based lubricants. In general, vegetable oils are highly attractive substitutes for petroleum-based oils because they are environmentally friendly, renewable, less toxic and readily biodegradable. Consequently, currently, vegetable based oils are more potential candidates for the use in industry as lubricants/MWFs. Many investigations are in progress to develop new bio based cutting fluids based on various vegetable oils available around the world.

The objective of this project is to conduct research and study of the behavior of crude palm oil (CPO) as cutting fluid. In addition, it also aims to investigate the surface roughness resulted from the operation of milling machining using this crude palm oil as the cutting fluid. Furthermore, at the final stage of the project, a comparison of surface roughness on workpiece between machining using crude palm oil and conventional cutting fluid and also the result from dry machining are being done.

The acquired result from the experiments conducted shows a very positive and promising outcome. However, into the bargain, the author believes that given more time and funds, and with further improvements in the conducting of the experiments and the facilities, the outcome of the project can be a greater success.

ACKNOWLEDGEMENT

In the name of ALLAH, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in his will and given strength, I had managed to complete this Final Year Project successfully.

A lot of experiences have been gain and lessons learned during this period of project and I am in debt to so many people who had helped to make this project successful. My deepest gratitude goes to my dedicated supervisor, Associate Professor Dr. Mustafar Sudin whose continuous support and advice have truly been a great inspiration for me to work on this project.

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Thank you and best regards,

Hairani Sudin

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CHAPTER 1

PROJECT BACKGROUND

1.0 PROJECT BACKGROUND

This project aims to investigate and study the cutting behavior of crude palm oil (CPO) as a cutting fluid in milling machining as compared to the conventional cutting fluid and dry machining. The conventional cutting fluid used throughout the project is Solkut cutting fluid. The sample materials used to conduct the project are stainless steel and aluminum. Details explanation on the experiment conducted will be shown in the Methodology section, **CHAPTER 3**.

1.1 Problem statement

1.1.1 Problem identification

Due to growing environmental concerns, vegetable oils are solidly finding their way into being the replacement as the cutting fluids of choices for machining applications. These oils are indeed offering significant environmental benefits with respect to resource renewability, biodegradability as well as providing satisfactory performance in a wide array of applications. Synthetic ester based fluids may also offer these said advantages but, their cost can also be prohibitively high. However, formulating with vegetable oils especially the highly saturated oils present unique challenges including the low temperature viscosities, oxidative, and hydrolytic instabilities problems associated with the triglyceride. Palm oil along with some other common and commercially available vegetable oils will be reviewed as to their applicability and define those issues that may find these oils unsuitable or restricted to limited applications [1].

1.1.2 Significance of the project

This project assesses the performance of crude palm oil, a type of bio-based oil as a cutting fluid compared to the conventional cutting fluids and dry machining. While the conventional cutting fluids have its own properties, the author would like to highlight the properties of bio-based oil:

- Biodegradable
- Renewable resource
- Provide good lubrication
- Easy disposal
- Affordable application cost
- Non-toxic
- Low health and safety risks [1].

1.2 Objectives

There are two (2) objectives in conducting this project:

1. To investigate the quality of surface finish when using crude palm oil (CPO) as a cutting fluid in milling operation on two different materials; stainless steel and aluminum.
2. To compare the result of surface finish between crude palm oil (CPO), conventional cutting fluid and dry machining in milling operation.

1.3 Scope of study

This project focused on three (3) scopes of studies:

1. To study and understand the fundamental theory of cutting fluids.
2. To study the essential properties of cutting fluids and its effect in milling machining.
3. To do research on the recent study conducted elsewhere in this field through relevant International Journal, Technical Manual, Text Book, Internet, etc.

CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

2.1 Cutting fluids

Cutting fluids are various fluids that are used in machining to cool and lubricate the cutting tool. There are various kinds of cutting fluids, which include oils, oil-water emulsions, pastes, gels and mists. They may be made from petroleum distillates, animal fats, plant oils, or other raw ingredients [2].

There are four general types of cutting fluids commonly used in machining operations:

1. Oils
2. Emulsions
3. Semi synthetics
4. Synthetics [3].

Oils (also called straight oils) including mineral, animal, vegetable, compounded, and synthetics oils typically are used for low-speed operations where temperature rise is not significant.

Emulsions (also called soluble oils) are a mixture of oil and water and additives, generally are used for high-speed operations because temperature rise is significant. The presence of water makes emulsions very effective coolants.

Semi synthetics are chemical emulsions containing little mineral oil, diluted in water, and with additives that reduce the size of oil particles, making them more effective. Synthetics are chemical with additives, diluted in water, and contain no oil [3].

There are four basic methods of cutting fluids applications in machining:

1. Flooding
2. Mist
3. High pressure systems
4. Through the cutting tool system [4].

Flooding is the most common method. Flow rates typically range from 10 L/min for single-point tools to 225 L/min per cutter for multiple-tooth cutters, such as in milling. In some operations, such as drilling and milling, fluid pressures in the range of 700 to 14000kPa are used to flush away the chips produced to prevent interfering with the operation.

Mist supplies fluid to inaccessible areas, similar to using an aerosol can, and provides better visibility of the workpiece being machined (as compared to flood cooling). It is effective particularly with water-based fluids at air pressures of 70 to 600kPa. However it has limited cooling capacity. Mist application requires venting to prevent the inhalation of airborne fluid particles by the machine operator and others nearby.

Through the high-pressure systems application, with the increasing speed and power of modern, computer-controlled machine tools, heat generation in machining has become a significant factor. Particularly effective is the use of high-pressure refrigerated coolant systems to increase the rate of heat removal from the cutting zone. High pressures also are used in delivering the cutting fluid using specially designed nozzles that aim a powerful jet of fluid to the zone, particularly into the clearance or relief face of the tool. The pressures employed, which are usually in the range 5.5 to 36MPa, act, as a chip breaker in situations where the chips produced would otherwise be long and continuous, interfering with the cutting operation. In order to avoid damage to the workpiece surface by impact from any particles present in the high-pressure jet, contaminant size in the coolant should not exceed 20 μm. proper and continuous filtering of the fluid also is essential to maintain quality [4].

For a more effective application through the cutting tool system, narrow passages can be produced in cutting tools, as well as in tool holders, through which cutting fluids can be applied under high pressure. The cutting fluids applied in machining processes basically have three characteristics:

1. Cooling effect
2. Lubrication effect
3. Taking away formed chip from the cutting zone [4].

The cooling effect of cutting fluids is the most important parameter. It is necessary to decrease the effects of temperature on cutting tool and machined workpiece. Therefore, a longer tool life will be obtained due to less tool wear and the dimensional accuracy of machined workpiece will be improved.

The lubrication effect will cause easy chip flow on the rake face of cutting tool because of low friction coefficient. This would also result in the increased by the chips. Moreover, the influence of lubrication would cause less built-up edge when machining some materials such as aluminum and its alloys. As a result, better surface roughness would be observed by using cutting fluids in machining processes.

Taking away formed chip from the cutting zone. It is also necessary to take the formed chips away quickly from cutting tool and machined workpiece surface. Hence the effect of the formed chip on the machined surface would be eliminated causing poor surface finish. Moreover, part of the generated heat will be taken away by transferring formed chip [4].

The selection of cutting fluids in machining processes depends on various factors:

1. Type of machining processes
2. Type of machined workpiece material
3. Type of cutting tool material [4].

The most important parameter in the selection of cutting fluids is the characteristics of machining process. Variety of machining processes would indicate relation between workpiece material-cutting tool-chip combinations. The excellent literature survey in cutting fluids application provided same important data; machining processes were put in order according to the amount of usable cutting fluids quantity from the smallest amount to the highest amount:

1. Grinding
2. Cutting with saw
3. Turning
4. Planning and shaping
5. Milling
6. Drilling
7. Threading (using high cutting speed and low feed rate)
8. Threading operation with shape tools
9. Boring
10. Drilling deep holes [4].

The heavy machining processes generally require middle or heavy cutting oils. Heavy cutting oils or the oils whose chemical components heavier active oils must be used in the horizontal broaching of steel.

Emulsions and solutions can be used in vertical surface broaching operation, however the application of oil type cutting fluid would be more suitable.

In threading operation, the interface between cutting tool and workpiece is small but continuous. For this operation cooling characteristic of cutting fluid is required.

Drilling process may be more problematic. Cutting speed in drilling operation is generally low due to two cutting edges of drill tool. Moreover, the geometry of formed chip is different. Therefore the cooling effect of cutting fluid is more important in drilling process. In conventional drilling operation, emulsion oils and sulphur or chlorine additive mineral oils should be selected. These fluids can reduce friction and as a result less heat generation will be noticed. Using advanced drill tools such as drill containing holes for cutting fluid application can be preferred.

In turning, milling and grinding, machining processes water based cutting fluids are more suitable due to using new cutting tool materials such as hard metals and high cutting speeds. The contact period between cutting tool and workpiece material is small when high cutting speeds are used. Therefore penetration of cutting fluid will not be sufficient. Water based cutting fluids will reduce the effect of generated heat on cutting tool wear.

The other factor in selection of suitable cutting fluids in machining processes is the type of workpiece material. The application of cutting fluids should provide easy machining operations in all materials.

In steel machining operation, generally the high pressure containing an additive cutting fluids are used. In stainless steel machining, high pressure cutting oils should be selected. Work hardening properties in some steels would cause some problems during machining operation.

During machining of aluminum and aluminum alloys, high temperatures do not occur. Waterless cutting fluids prevent the formation of “built up edge”, however this type of cutting fluids must be non-active (leaving no stain).

The third influential parameter for selection of cutting fluid in machining processes is the cutting tool material. High-speed steel cutting tools can be used with all type of cutting fluids. However, waterless cutting fluids are preferred when difficult-to-cut materials are machined [4].

2.2 Dry machining

Cutting fluids functions are not available in dry machining operations. This means that there is more friction and adhesion between tool and workpiece. Tools and workpieces are subjected to greater thermal load. This may result in higher levels of tool wear, e.g. in increased crater formation when steel materials are machined using uncoated carbides. However, dry cutting may also show positive effects such as thermal shock reduction and thus in the formation of comb-cracks. Higher machining temperatures influence also chip formation. This may results in both ribbon chips and snarls chips [5].

There have been recent requirements to reduce cutting fluid in mass production factories, because of the high cost and harmfulness of coolant. Near dry machining makes it possible to machine with conventional cutting parameters, without using much coolant [6].

Dry and near-dry machining won't replace traditional metalworking fluid technology anytime soon, but they do offer advantages for some niche markets.

The major benefits of dry and near-dry machining:

1. Alleviating the environmental impact of using cutting fluids, improving air quality in manufacturing plants, and reducing health hazards.
2. Reducing the cost of machining, operations, including the cost of maintenance, recycling, and disposal of cutting fluids.
3. Further improving surface quality [3].

Dry machining also is a viable alternative. With major advances in cutting tools, dry machining has been shown to be effective in various machining operations (especially turning, milling, and gear cutting) on steels, steel alloys, and cast irons, but generally not for aluminum alloys.

Dry machining research and practice is moving forward for two major reasons:

1) The potential reduction in cost by minimizing or eliminating the use of cutting fluids which are expensive to use and maintain, and

2) The health and environmental benefits of minimizing metalworking fluid use, termed “green machining”.

Dry machining provides for significant cost savings, including the cost associated with purchasing metalworking fluids and biocides added to minimize microbial growth, maintaining equipment used to deliver metalworking fluids to the work surface, and ultimate disposal. Spent metalworking fluid is a waste stream of growing concern, due to the increasing costs of treatment and disposal that in many cases exceed the original purchased price [7].

2.3 Crude palm oil

Palm oil is dark yellow to yellow-red oil (high carotene content) of vegetable origin obtained by pressing or boiling the flesh of the fruit of the oil palm (Elaeisguineensis). Palm oil differs from palm kernel oil, the latter being obtained from the kernels of the oil palm [8]. It is rich in carotenoids (pigment found in plants and animals) from which it derives its deep red color and the major component of its glycerides is the saturated fatty acid palmitic; hence it is a viscous semi-solid, even at tropical ambient, and a solid fat in temperate climates [9].

The fruit are made up of an outer skin (the exocarp), a pulp (mesocarp) containing the palm oil in fibrous matrix; a central nut consisting of a shell (endocarp); and the kernel, which itself contains oil. From **Figure 1** we can see the physical appearance of the palm fruit and The **Figure 2** below shows the structure of the palm fruit.

Figure 1: Physical appearance of palm fruit

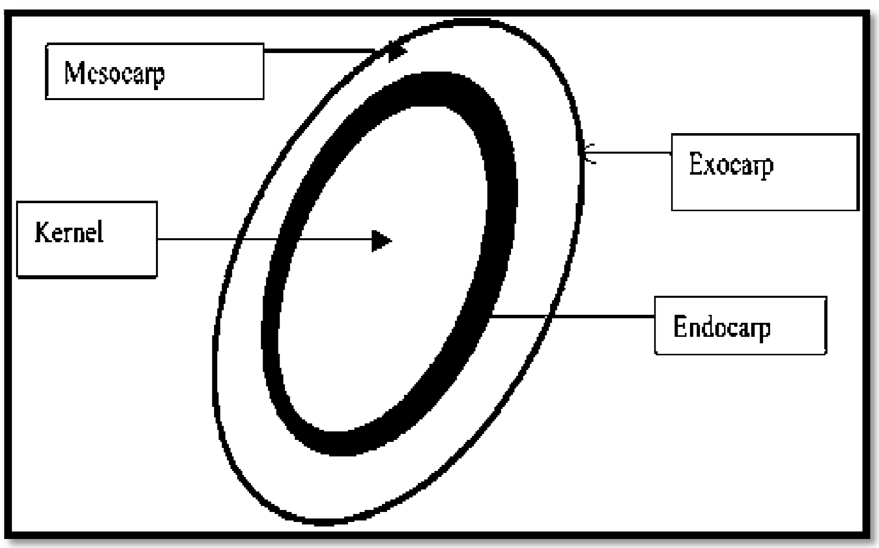


Figure 2: Structure of the palm fruit [9]

The below figure shows the ideal composition of palm fruit bunch:

Table 1: Ideal composition of palm fruit bunch [9]

Bunch	**Composition**
Bunch weight	23/27 kg
Fruit/bunch	60-65 %
Oil/bunch	21-23 %
Kernel/bunch	5-7 %
Mesocarp/bunch	44-46 %
Mesocarp/fruit	71-76 %
Kernel/fruit	21-22 %
Shell/fruit	10-11 %

Oils and fats spoil by readily becoming rancid. Rancidity is promoted by light, atmospheric oxygen and moisture and leads to changes in odor and taste. The palm oil has a limited time for storage, as given in the table below:

Table 2: The maximum duration for storage for palm oil [8]

Temperature	**Max. Duration of storage**
30 °C	6 months

The general principles of preservation and processing methods of palm oil include:

1. Destruction of enzymes (a complex organic substance which in solution produces fermentation and chemical changes in other substances apparently without undergoing any change itself) in the raw material and contaminating microorganisms by heat (sterilization) during processing.
2. Elimination of as much water as possible from the oil to prevent microbial growth (bacterial activity, or disease causing germs) during storage. The oil therefore has a long shelf life due to its low moisture content.

3. Proper packaging and storage of the extracted oil to slow down the chemical deterioration (rancidity) [9].

Palm fruit contains about 56 percent oil (25 percent on a fresh fruit bunch basis), which is edible with no known toxins [9].

Palm oil is processed to produce edible fats (margarine), soaps and candles and is used in pharmacy and cosmetics and as an important raw material in oleochemistry. And now, more experiments are conducted to prove the use of palm oil in the machining applications [8].

All fats and oils have a particular density (approx. $0.9 g/cm^3$). With a rise in temperature, however, density diminishes, thereby leading at the same time to an increase in volume. This behavior is described by the coefficient of cubic expansion and is known as thermal dilatation. As a rule of thumb, oils may be expected to increase in volume by 1 % of their total volume for each 14 °C temperature increase.

Palm oil requires particular temperature conditions for its storage. It may suffer damage and reduction in utility value if the temperature exceeds or falls below certain limit values. Palm oil has a relatively high solidification point/range of 41-31 °C and thus must be heated by a few °C per day; otherwise the risk of rancidity and other negative changes arises. The rate of heating should be no greater than 8°C/day. Too great or rapid an increase in temperature entails considerable losses in quality.

Fats and fatty oils are insoluble in water. However, contact with water may give rise to soluble lower fatty acids and glycerol, which cause rancidity together with changes in color (yellow to brown), odor and taste as well as gelling and thickening.

Palm oil displays 3rd order biotic activity, where respiration processes (external respiration) is suspended, but in which biochemical, microbial and other decomposition processes still proceed. The oil may also ignite spontaneously in conjunction with sawdust or material residues [8].

Vegetables oils as in palm oil can and have been used as lubricants in their natural forms. On the negative side, vegetable oils in their natural form lack sufficient oxidative stability for lubricant use. Low oxidative stability means, if untreated, the oil will oxidize rather quickly during use, becoming thick and polymerizing to a plastic-like consistency. Chemical modification of vegetable oils and/or the use of antioxidants can address this problem, but increase the cost. Chemical modification could involve partial hydrogenation of the vegetable oil and a shifting of its fatty acids. Another negative to vegetable oils is their high pour point (the temperature at which oil loses fluidity and does not flow). This problem too can be addressed by winterization, addition of chemical additives (pour point suppressants) and/or blending with other fluids possessing lower pour points [10].

Vegetables oils cannot meet most lubrication performance needs without additives. Thus, in term of concern of environmental issues, some researchers conducted the effect of antiwear additives in vegetable oils promoted the newly synthesized additives, dibutyl 3.5-di-t-butyl 4-hydroxy benzyl phosphonate (DBP) as an excellent antiwear performance compare to the conventional additives, TCP. Meanwhile, two additives are used to study oxidation and low temperature stability of vegetable oil-based lubricants, which are zinc diamyldithiocarbamate (ZDDC) and antimony dialkyldithiocarbamate (ADDC) [11]. **Table 3** shows some additives that have been used in vegetable oil.

Table 3: Additives in vegetable oils [11]

Additives	Function
Zinc diamyldithiocarbamate (ZDDC) Antimony dialkyldithiocarbamate (ADDC)	Anti-wear and antioxidant abilities
Zinc-Dialkyl-Dithio-Phosphate (ZDDP)	Anti-wear/extreme pressure (AW/EP)
S-[2-(acetamido) thiazol-1-yl] dialkyldithiocarbamates	Anti-wear
Palm oil methyl ester (POME)	Anti-wear
Dibutyl 3.5-di-t-butyl-4-hydroxy benzylphosphate (DBP)	Anti-wear
Butylatedhydroxy anisole (BHA), Butylatedhydroxy toluene (BHT), Mono-tert-butyl-hydroquinone (TBHQ), propylgallate (PG)	Chain-breaking antioxidants
Zincdithiophosphates (DTP) Dithiocarbamates (DTC)	Peroxide decomposers antioxidant

2.4 Conventional cutting fluid

The properties of conventional cutting fluid as being used in the machining operations are:

Table 4: Properties of conventional cutting fluid [12]

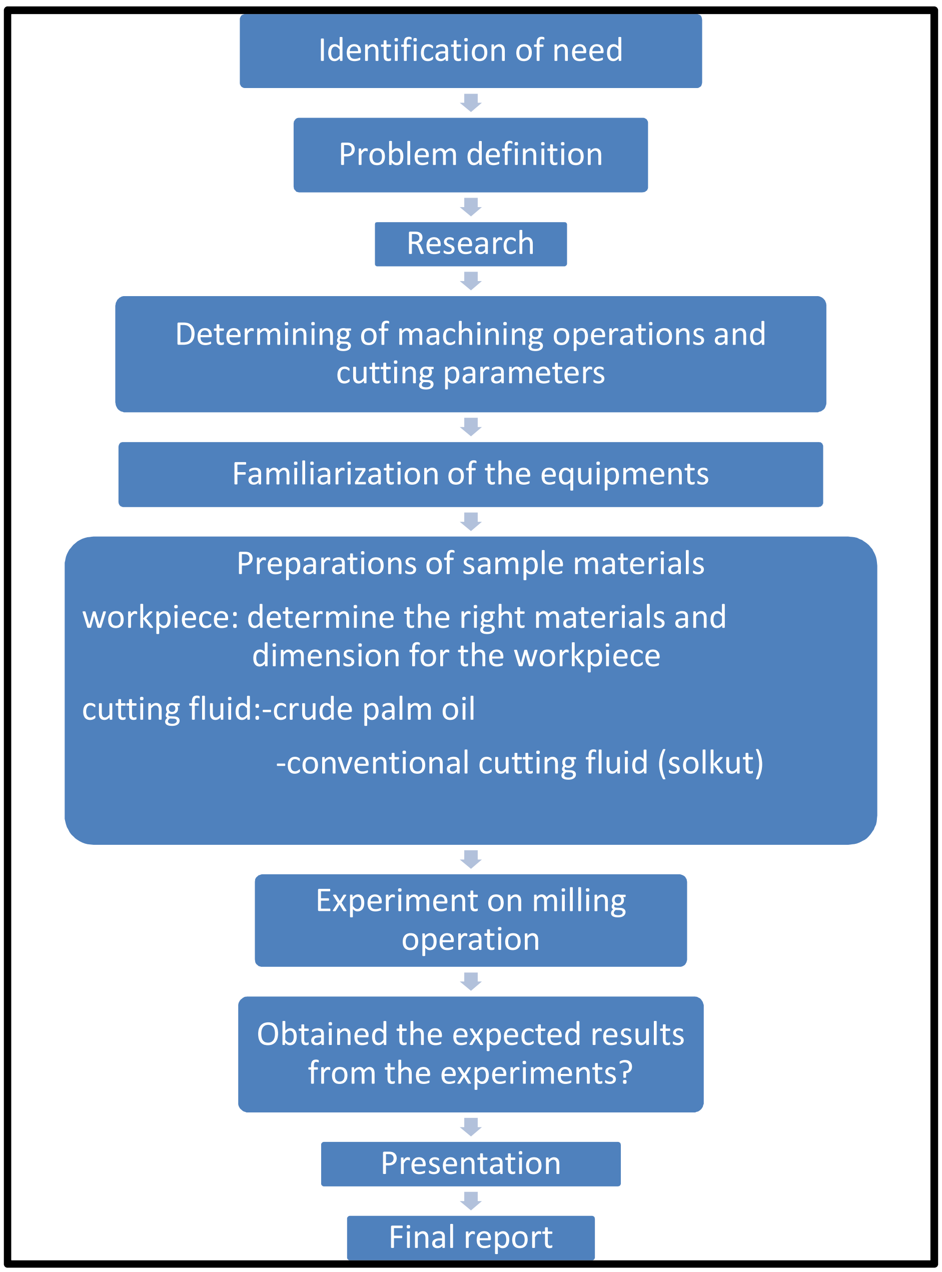
Product name	Solkut 2140
Description of product	Propriety Soluble Metal Working Fluid
Physical and chemical properties	
State	Liquid
Color	Amber
Odor	Mild
Oxidizing	Non-oxidizing (by EC Criteria)
Solubility	Soluble in water and most organic solvents
Viscosity	Viscous (>40 cSt)
Boiling point	>100 ^{o}C
Flash point	100 ^{o}C
Autoflammability	>150 ^{o}C
Relative density	0.95
pH	9.3
Viscosity test method	Kinematic viscosity in 10-6 m^2/s at 40 ^{o}C

CHAPTER 3

METHODOLOGY

3.0 METHODOLOGY

3.1 Process flow chart



3.2 Selection of sample materials and operations

There are three factors and one operation involve in this project:

1. Cutting fluids

   The author used two different cutting fluids in order to compare the end results in the end of the project, which are:

   - Conventional cutting fluid: Solkut 2140
   - Crude palm oil (CPO)
   - Dry cutting

2. Workpiece materials

   There are two different materials used in this project:

   - Aluminum
   - Stainless steel

3. Workpiece shape

   Aluminum and stainless steel with dimensions of 100mm x 100mm x 10mm.

4. Machining operation

   Face milling with different depths of cut 0.5mm, 0.75mm and 1.0mm.

3.3 Milling machining and parameters

3.3.1 Milling machining

Milling is the process of cutting away material by feeding a workpiece past a rotating multiple tool cutters. The cutting action of the many teeth around the milling cutter provides a fast method of machining. The machined surfaced may be flat, angular, or curved. The surface may also be milled to any combination of shapes [13].

Figure 3 below illustrates the process at the cutting area. Milling is versatile for a basic machining process, but because the milling setup has so many degrees of freedom, milling is usually less accurate than turning or grinding unless especially rigid fixturing is implemented [14].

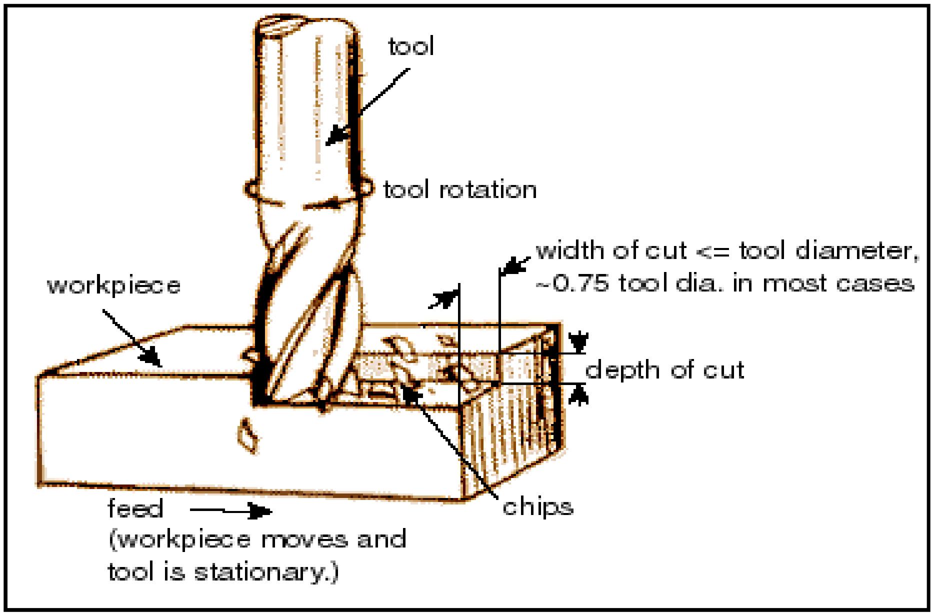


Figure 3: Process at cutting area [14]

In concept, milling is very straightforward. A cutter is held in a chuck, which rotates at a controlled speed. The cutter is suspended over a work surface whose location can be precisely controlled. The part to be machined is securely fastened to the work surface, and the work surface is moved underneath the cutter. Appropriate choices of cutter type, depth of cut and speed determine the final shape [15].

Milling includes a number of machining operations including: slotting, drilling, reaming, facing, and pocket removal. A cutting tool that revolves around central axis carries out these operations. A workpiece or stock is clamped on the bed, and the cutting tool moves into it, removing material as it goes. Either the tool itself moved, usually it moves along the axis of the tool or the bed the stock is attached to moves, bringing the workpiece into contact with the tool [16].

Looking on milling performance, many factors need to be considered for successful machining. It can be seen in **Figure 3** that several factors influenced the machining performance when milling of any material. In addition, **Table 5** shows the machining parameters chosen for conducting milling operation in this project while in **Table 6** we can see the standard parameters for the cutting tool specifications that were used throughout this project.

3.3.2 Influences of radial and axial depths of cut

Flute engagement in the milling forces is important because it influences the forces directly. However, the forces also influenced by the radial and axial depths of cut because radial and axial depths of cut affect the width and length of the "contact area" in the feed and rotational directions, respectively. That is, the deeper the radial or axial depths of cut, the more flutes will be engaged, and thus the lengths of the engaged flutes.

- **The radial depth of cut** plays an important role in milling forces because as the radial depth of cut is increased, the "contact area" increases in the rotational direction, and the forces becomes larger.
- **Axial depth of cut** is another factor influencing the "contact area" since it affects the axial cutting length of the area. That is, when the axial depth of cut is increased, the length of engaged flutes increases, and the milling forces also increase [17].

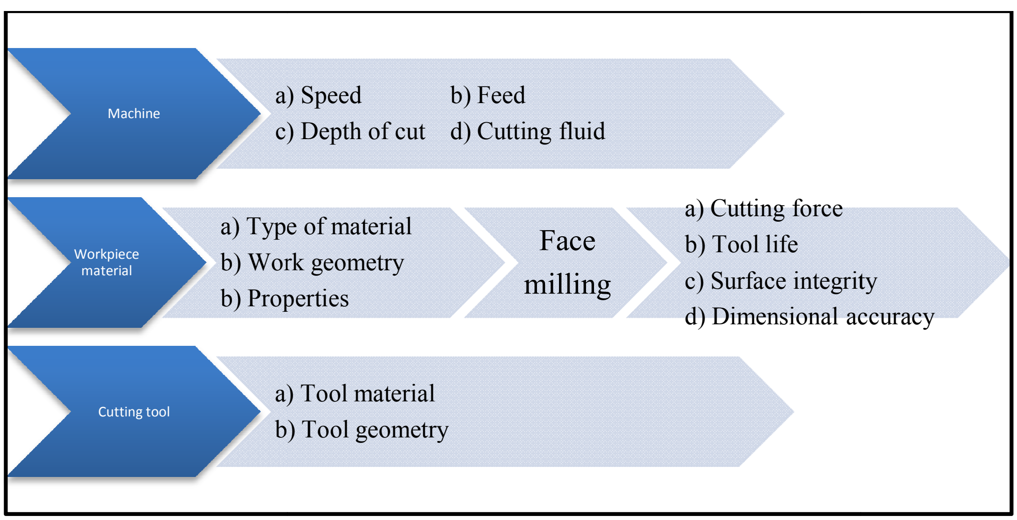


Figure 4: Factor influencing the face milling of materials [11]

Table 5: Machining parameters of milling operation [3]

	Aluminum	**Stainless steel**
Cutting speed (*rpm*) *	1000	1000
	1000	1000
	1000	1000
Depth of cut (*mm*)	0.5 0.75 1.0	0.5 0.75 1.0
Feed (*mm/tooth*)	0.15	

Using Titanium nitride coated carbide-cutting tool

Table 6: Cutting tool specifications [18]

Chemical name	Titanium Carbonitride with Cobalt-Nickel
Chemical family	Refractory Metal Carbides
Tooth	Multiple teeth-3 teeth

3.4 Materials preparations

Materials to be used in conducting the project are prepared accordingly:

1. Solkut is already available in the machining lab and CPO was obtained from the palm oil factory. Both cutting fluids are being used straightaway for the machining.
2. Workpieces used are of two different materials: aluminum and stainless steel. The aluminum workpieces are provided at the machining lab while the stainless steel workpieces was obtained from the outside vendor. The **Figure 4** below shows the six workpieces used in conducting this project.

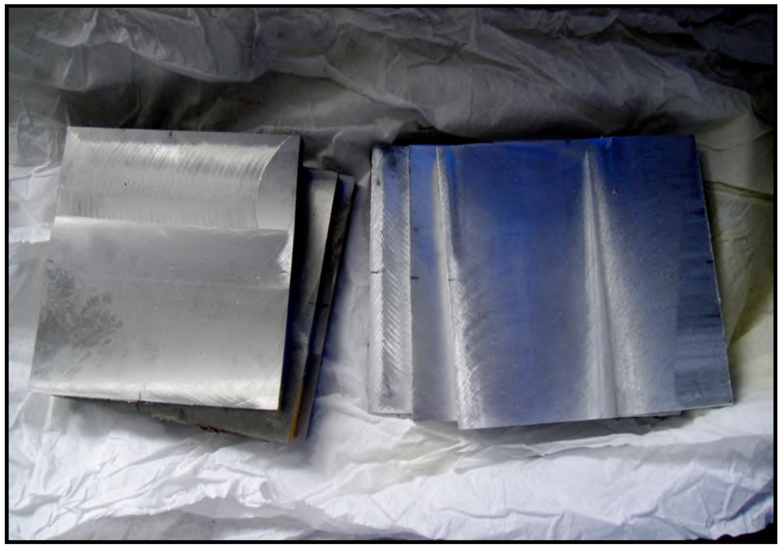


Figure 5: Workpieces used in the machining operations

3.5 Equipments used

There are two major equipments used in conducting this project; milling machine and surface profiler, in line with the topic chosen for the project; The Study into the Effects of CPO as Cutting Fluids in Milling Machining.

Table 7: The equipment used and their function

Equipment	Function
Surface profiler	To measure the surface roughness
Conventional milling machine	To conduct milling machining

Figure 6: Conventional milling machine

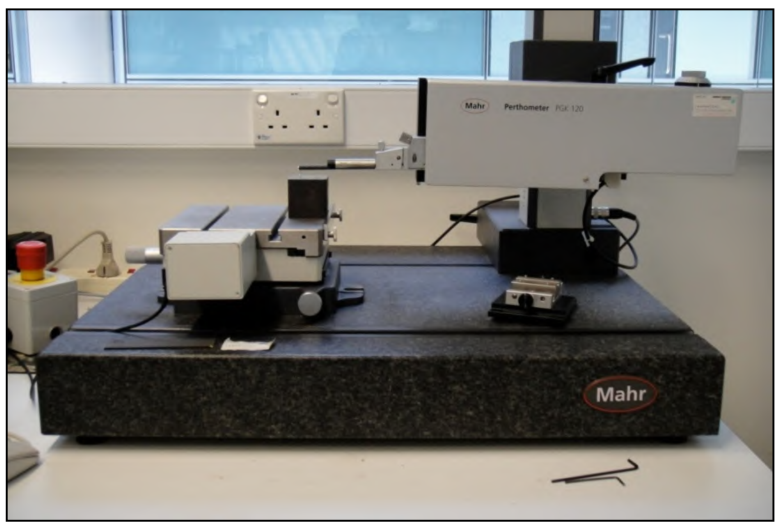


Figure 7: Surface profiler

3.6 Workpiece properties

1. Aluminum

Table 8: The properties of Aluminum [19]

Physical properties	
Density	2.6989 g/cm^3
Mechanical properties	
Hardness, Vickers	15.0
Modulus of Elasticity	68.0GPa
Poissons Ratio	0.360
Shear Modulus	25.0GPa
Electrical Properties	
Electrical Resistivity	0.00000270 ohm-cm
Magnetic Susceptibility	6.00e-7
Critical Magnetic Field Strength, Oersted	101.9 - 107.9
Critical Superconducting Temperature	1.73 - 1.77
Thermal Properties	
Heat of Fusion	386.9 J/g
Heat of Vaporization	9462 J/g
Specific Heat Capacity	0.900 J/g-°C
Thermal Conductivity	210 W/m-K
Melting Point	660.37 ^{o}C

2. Stainless steel

Table 9: The properties of Stainless steel [20]

Physical properties	
Density	8.00 g/cm^3
Mechanical properties	
Hardness, Brinell	123
Hardness, Knoop	138
Hardness, Rockwell B	70
Hardness, Vickers	129
Tensile Strength, Ultimate	505MPa
Tensile Strength, Yield	215MPa
Elongation at Break	70.0 %
Modulus of Elasticity	193 - 200GPa
Poissons Ratio	0.290
Charpy Impact	325 J
Shear Modulus	86.0GPa
Electrical properties	
Electrical Resistivity	0.0000720 ohm-cm
Magnetic Permeability	0.000116 ohm-cm
Thermal properties	
Specific Heat Capacity	0.500 J/g-°C
Thermal Conductivity	16.2 W/m-K 21.5 W/m-K
Melting Point	1400 - 1455 °C
Solidus	1400 °C
Liquidus	1455 °C

Component elements properties	
Carbon, C	<= 0.080 %
Chromium, Cr	18.0 - 20.0 %
Iron, Fe	66.345 - 74.0 %
Manganese, Mn	<= 2.0 %
Nickel, Ni	8.0 - 10.5 %
Phosphorous, P	<= 0.045 %
Silicon, Si	<= 1.0 %
Sulfur, S	<= 0.030 %

3.7 Gantt chart

No.	Detail/Week	25/1 - 29/1	1/2 - 5/2	8/2 - 12/2	15/2 - 19/2	22/2 - 26/2	1/3 - 6/3	8/3 - 12/3	15/3 –19/3	22/3 - 26/3	29/3 - 2/4	5/4 - 9/4	12/4 - 16/4	19/4 - 23/4	26/4 - 30/4	3/5 - 7/5	10/5 - 14/5
1	Selection of Project Topic								Mid Semester Break								
	- Research for project background																
	-Submission of Form01																
2	Research work																
	-Preliminary interpretation																
	-Submission of Preliminary Report																
3	Project Work																
	Determining of machining operations & parameters																
4	Progress																

	Report and Seminar																
	Preparation of sample materials -workpiece																
	-Submission of Progress Report																
	- Seminar																
5	Project work continues																
6	Interim Report																
	-Evaluation and discussion of data																
	-Submission of Interim Report																
7	Oral Presentation																

Key milestone

Current status

Process

No.	Detail/Week	26/7 – 30/7	2/8 – 6/8	9/8 – 13/8	16/8 – 20/8	23/8 – 27/8	30/8 – 3/9	6/9 – 10/9	13/9 – 17/9	20/9 – 24/9	27/9 – 1/10	4/10 -8/10	11/10 – 15/10	18/10 – 22/10	25/10 – 29/10	1/11 – 5/11
1	Project work continue							Mid Semester Break								
	-Analysis and evaluation of data gathered															
	-Repeat procedure if necessary															
2	Progress Report 1															
	- Preparation of report															
	- Submission of Progress Report 1															
3	Project Work continue															
	-Final interpretation															

4	Progress Report 2														
	- Preparation of Progress Report 2														
	- Submission of Progress Report 2														
5	Project Work continue														
	- Preparation of dissertation														
	- Preparation of poster														
6	Poster Exhibition														
7	Submission of Dissertation														
	- Soft bound														
	- Hard bound														
8	Oral presentation														

CHAPTER 4
RESULT AND DISCUSSION

4.0 RESULT AND DISCUSSION

4.1 Data gathering and analysis

For this project, CPO was evaluated by the result provided from the surface roughness test. In the evaluation process, milling operation and surface roughness testing were conducted.

4.1.1 Machining operations

During the machining operations, milling machining using conventional milling machine has been successfully conducted. For the milling machining for both aluminum and stainless steel materials, 3 similar samples of similar dimensions were machined for each of the materials. The machining was conducted based on varying the depth of cut (d.o.c) for the three samples of each material. There are three different depth of cut being set up on the milling machine; 0.5 mm for the first sample, 0.75 mm for the second sample and 1.0 mm for the third sample and these depths of cut are being used throughout the machining operations. The results were divided in two sections; aluminum and stainless steel.

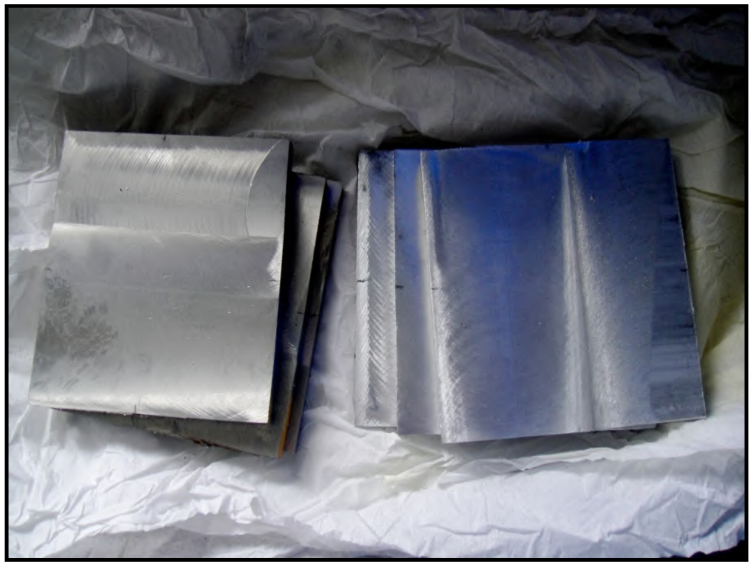


Figure 8: The workpiece machined by milling machining using crude palm oil (CPO) as cutting fluid

4.1.2 Measuring surface roughness

Surface roughness measuring machine was used to measure the surface roughness of the sample after being machine using milling machining. The measurements technique used are using the stylus instruments. Stylus instruments are based on the principle of running a probe across a surface in order to detect variations in height as a function of distance [21]. The value of R_a, the arithmetical mean deviation of the profile was measured for each sample. In order to get the best result, two locations were set up for the readings; DI and D2 and 10 readings were taken for each location. These actions were then repeated for each sample for each material.

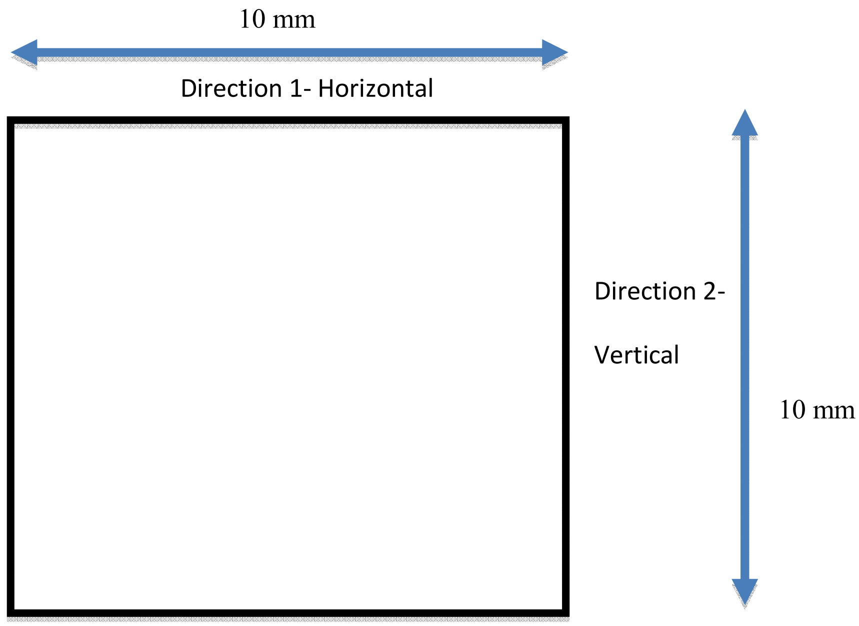


Figure 9: Direction of measurements of surface roughness on the workpiece

Table 10: Data of surface roughness of Stainless steel with depth of cut of 0.5 mm

Metal	Direction	Surface roughness using CPO as cutting fluid										Surface roughness using Solkut as cutting fluid										Surface roughness of dry machining									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Stainless steel	**D1**	5.46	3.20	0.58	4.35	5.97	5.56	1.42	1.43	4.72	5.75	2.48	1.19	1.08	1.23	0.91	0.99	0.98	1.84	1.32	2.93	7.24	5.30	2.79	2.56	2.99	3.44	3.84	3.96	3.65	4.39
	D2	6.59	6.37	6.43	6.58	6.63	6.72	6.70	6.62	6.33	5.92	3.33	2.92	1.33	8.47	1.85	1.76	1.01	0.73	1.71	0.78	5.71	3.43	1.93	3.77	6.57	5.74	6.76	8.25	7.28	9.44

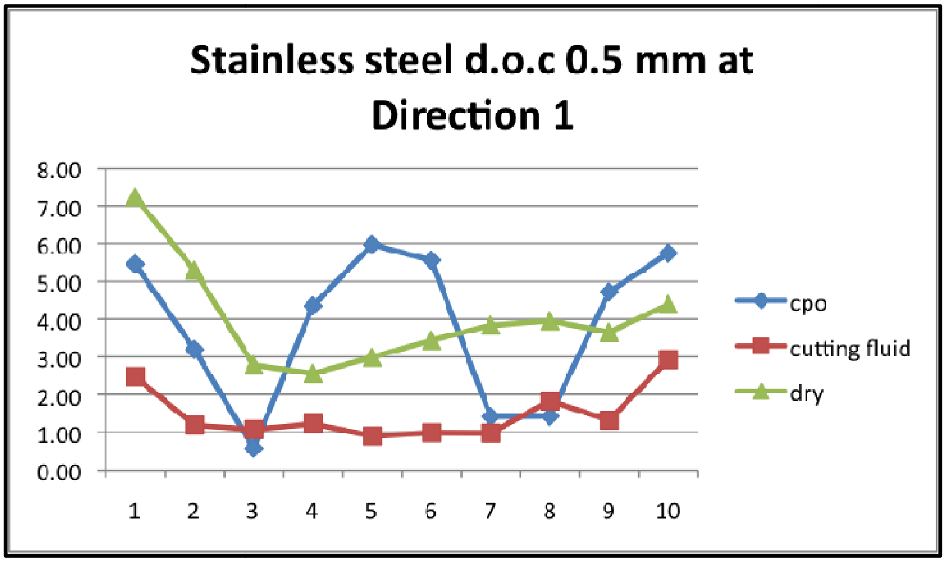


Figure 10: Surface roughness for Stainless steel with 0.5 mm depth of cut at Direction 1

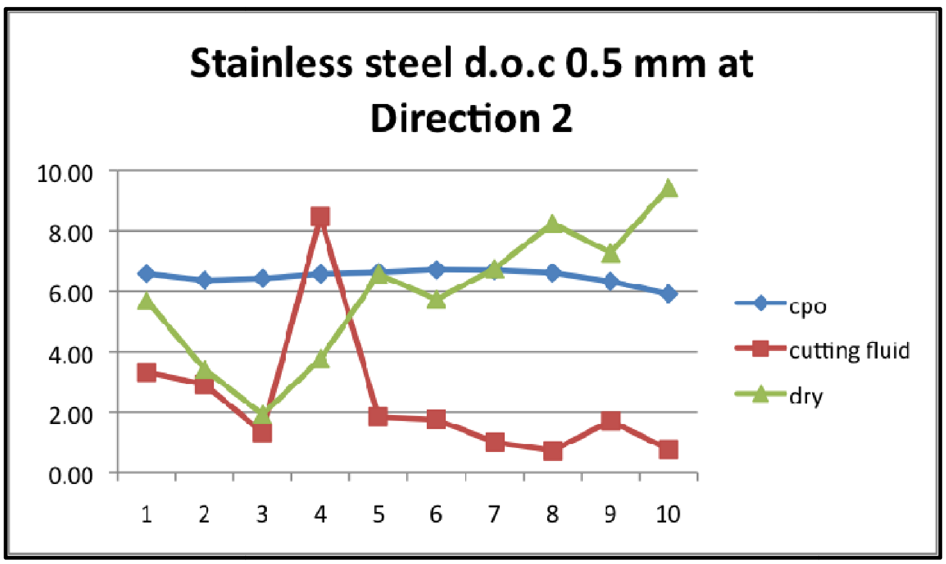


Figure 11: Surface roughness for Stainless steel with 0.5 mm depth of cut at Direction 2

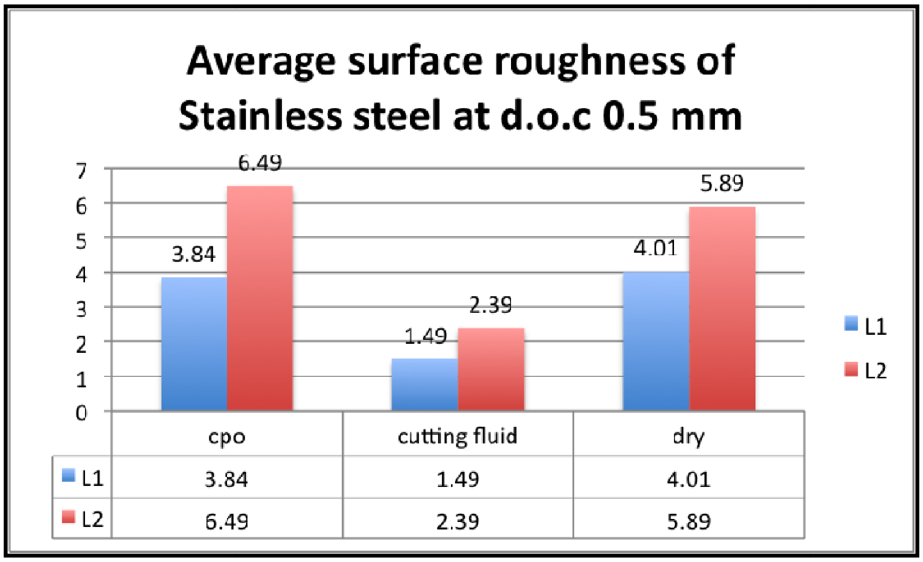


Figure 12: Average surface roughness for Stainless steel with 0.5 mm depth of cut

Table 11: Data of surface roughness of Stainless steel with depth of cut of 0.75 mm

Metal	Direction	Surface roughness using CPO as cutting fluid										Surface roughness using Solkut as cutting fluid										Surface roughness of dry machining									
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Stainless steel	D1	5.46	3.20	0.58	4.35	5.97	5.56	1.42	1.43	4.72	5.75	1.99	1.52	1.37	1.37	1.98	1.13	2.01	1.68	3.70	1.54	2.74	3.03	2.63	2.93	2.95	3.73	4.31	2.73	2.72	1.94
	D2	6.59	6.37	6.43	6.58	6.63	6.72	6.70	6.62	6.33	5.92	1.66	1.14	2.49	2.82	2.11	2.79	3.30	2.84	3.03	1.62	2.77	2.53	2.74	2.82	3.66	2.75	4.13	4.46	2.98	2.53

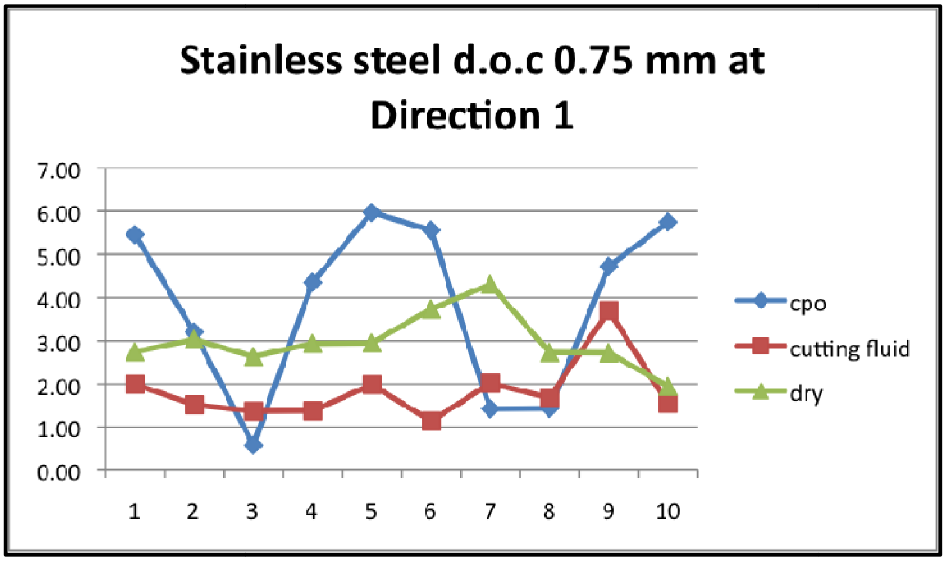


Figure 13: Surface roughness for Stainless steel with 0.75 mm depth of cut at Direction 1

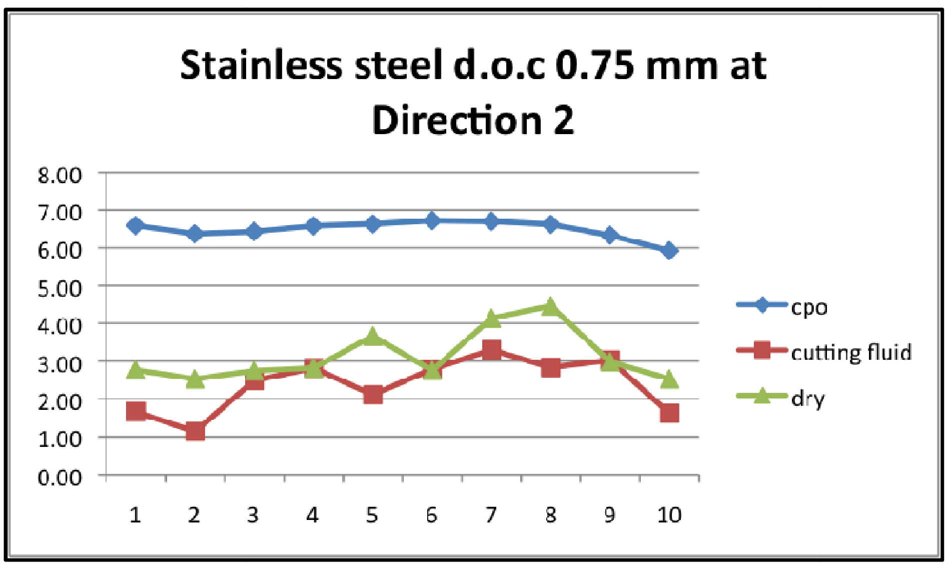


Figure 14: Surface roughness for Stainless steel with 0.75 mm depth of cut at Direction 2

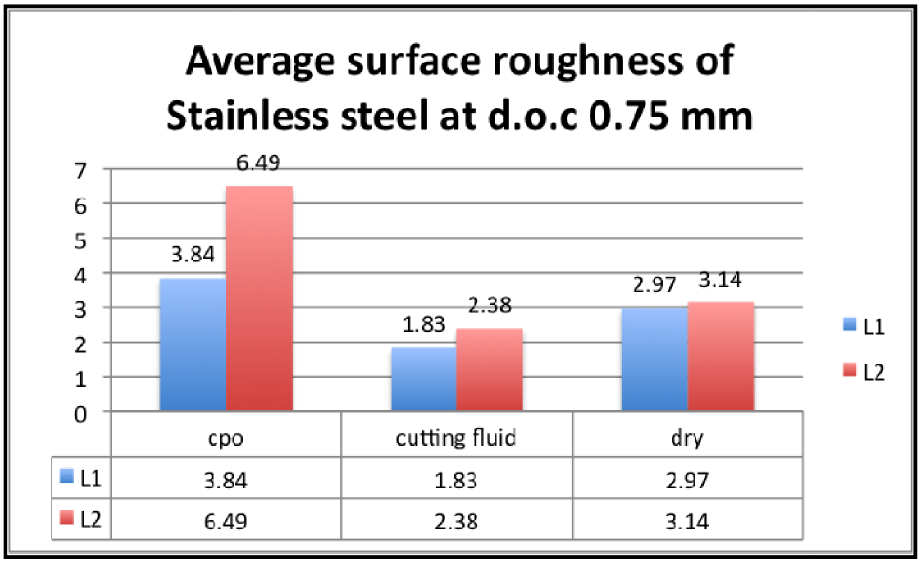


Figure 15: Average surface roughness for Stainless steel with 0.75 mm depth of cut

Table 12: Data of surface roughness of Stainless steel with depth of cut of 1.0 mm

Metal	Direction	Surface roughness using CPO as cutting fluid										Surface roughness using Solkut as cutting fluid										Surface roughness of dry machining									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Stainless steel	**D1**	5.46	3.20	0.58	4.35	5.97	5.56	1.42	1.43	4.72	5.75	2.16	1.92	1.87	6.07	1.60	1.92	1.68	1.41	2.02	1.87	5.42	3.48	1.80	1.98	1.92	6.44	3.91	3.51	3.60	4.21
	D2	6.59	6.37	6.43	6.58	6.63	6.72	6.70	6.62	6.33	5.92	2.52	4.71	1.29	1.92	2.18	2.24	2.49	7.90	2.18	2.12	5.75	4.16	3.27	4.71	6.81	5.88	5.54	3.84	3.49	1.71

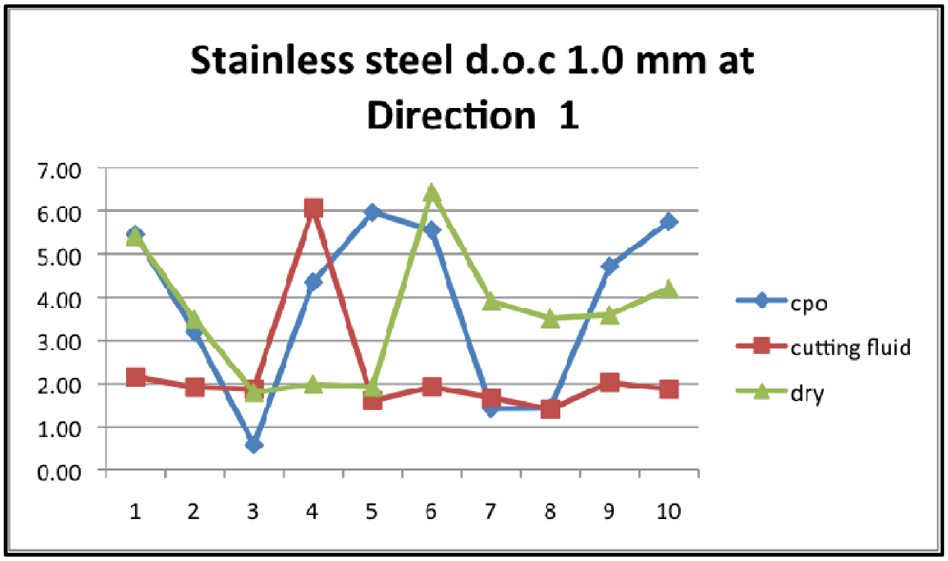


Figure 16: Surface roughness for Stainless steel with 1.0 mm depth of cut at Direction 1

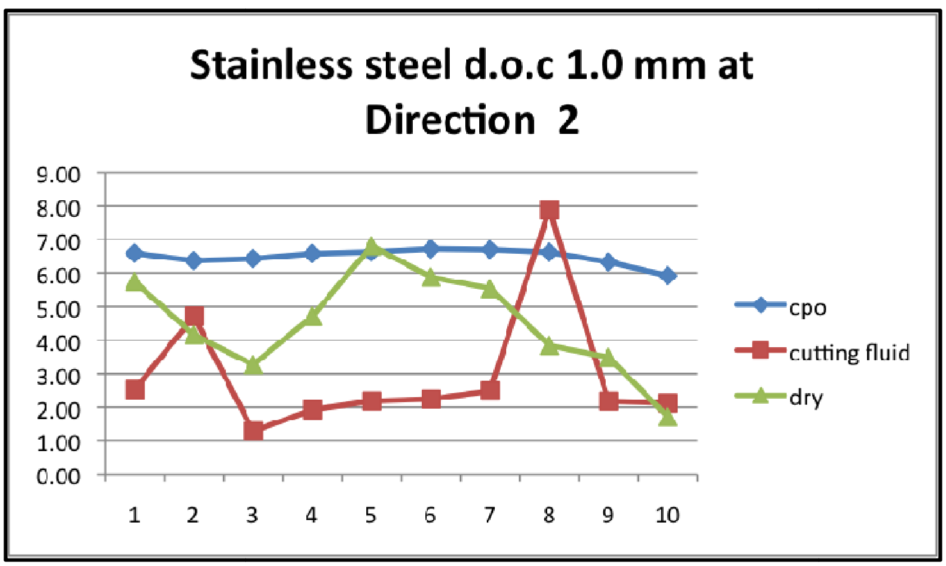


Figure 17: Surface roughness for Stainless steel with 1.0 mm depth of cut at Direction 2

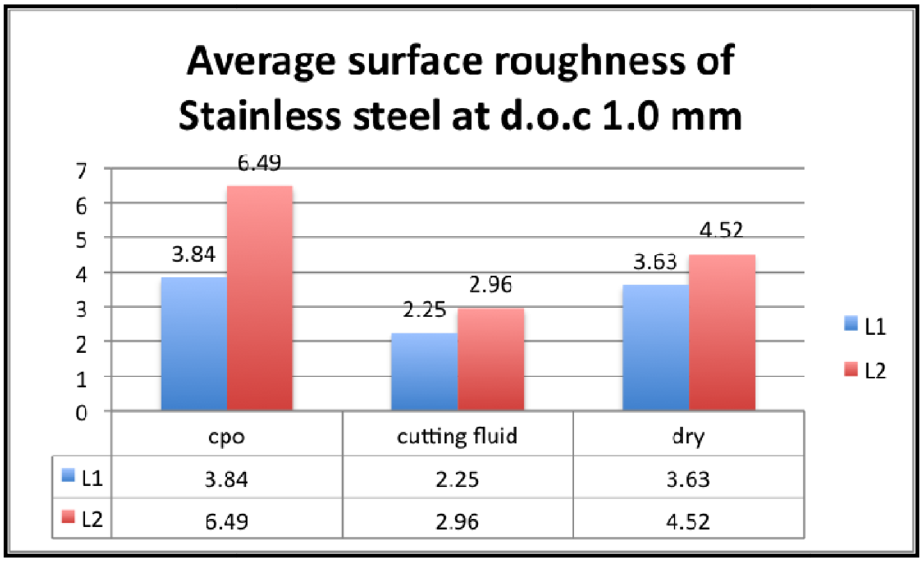


Figure 18: Average surface roughness for Stainless steel with 1.0 mm depth of cut

Table 13: Data of surface roughness of Aluminum with depth of cut of 0.5 mm

Metal	Direction	Surface roughness using CPO as cutting fluid										Surface roughness using Solkut as cutting fluid										Surface roughness of dry machining									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Aluminum	**D1**	2.81	2.72	2.64	2.44	2.59	2.64	2.70	2.68	2.43	3.15	2.26	2.44	3.68	2.18	2.83	4.36	3.83	2.61	3.65	1.47	3.87	1.29	2.23	1.88	3.05	2.16	2.19	2.14	1.69	2.71
	D2	3.97	3.97	1.76	1.86	4.17	2.33	5.43	7.06	8.97	6.28	5.59	4.55	6.84	4.31	4.78	8.69	1.76	2.37	1.84	2.21	3.38	1.61	1.76	1.80	2.67	4.83	6.18	3.71	3.43	8.85

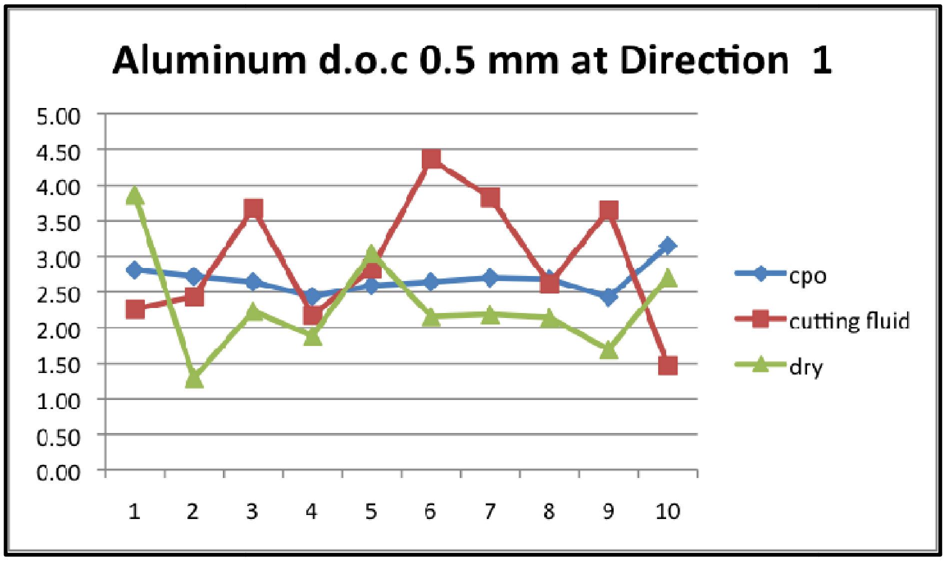


Figure 19: Surface roughness for Aluminum with 0.5 mm depth of cut at Direction 1

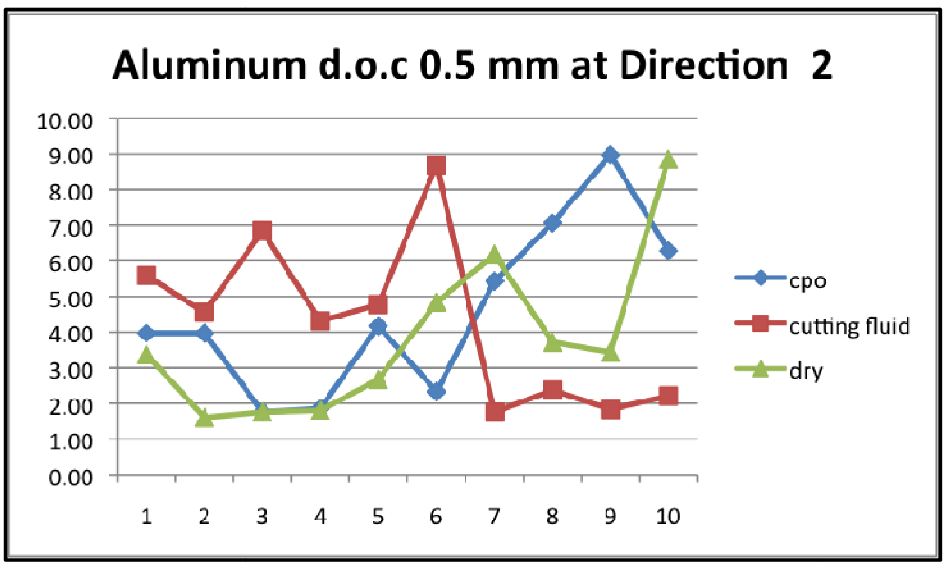
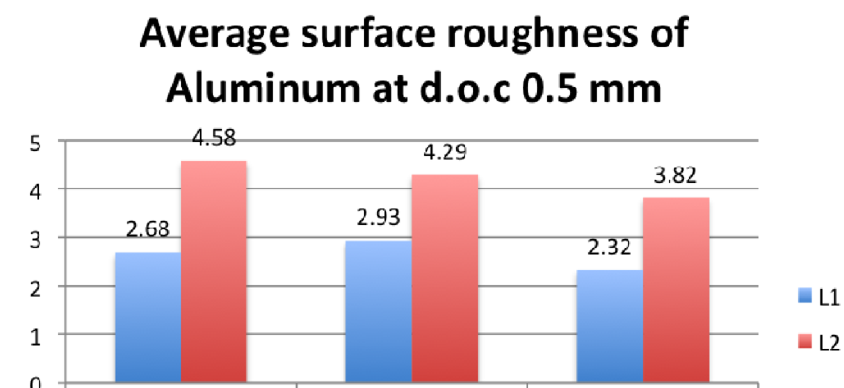


Figure 20: Surface roughness for Aluminum with 0.5 mm depth of cut at Direction 2



	cpo	cutting fluid	dry
L1	2.68	2.93	2.32
L2	4.58	4.29	3.82

Figure 21: Average surface roughness for Aluminum with 0.5 mm depth of cut

Table 14: Data of surface roughness of Aluminum with depth of cut of 0.75 mm

Metal	Direction	Surface roughness using CPO as cutting fluid										Surface roughness using Solkut as cutting fluid										Surface roughness of dry machining									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Aluminum	**D1**	2.75	1.91	0.60	2.53	2.47	2.80	2.50	1.60	1.17	4.33	2.99	2.80	2.74	2.24	3.21	2.82	3.15	4.36	5.07	4.79	8.83	9.78	4.48	4.41	4.41	4.48	5.08	3.58	3.67	6.46
	D2	3.03	3.02	2.97	1.85	1.78	2.08	2.23	2.58	2.69	2.23	2.29	4.88	3.60	2.75	2.90	3.58	4.68	3.82	3.87	3.33	4.16	7.93	7.83	7.58	5.80	4.91	4.29	4.50	5.31	4.98

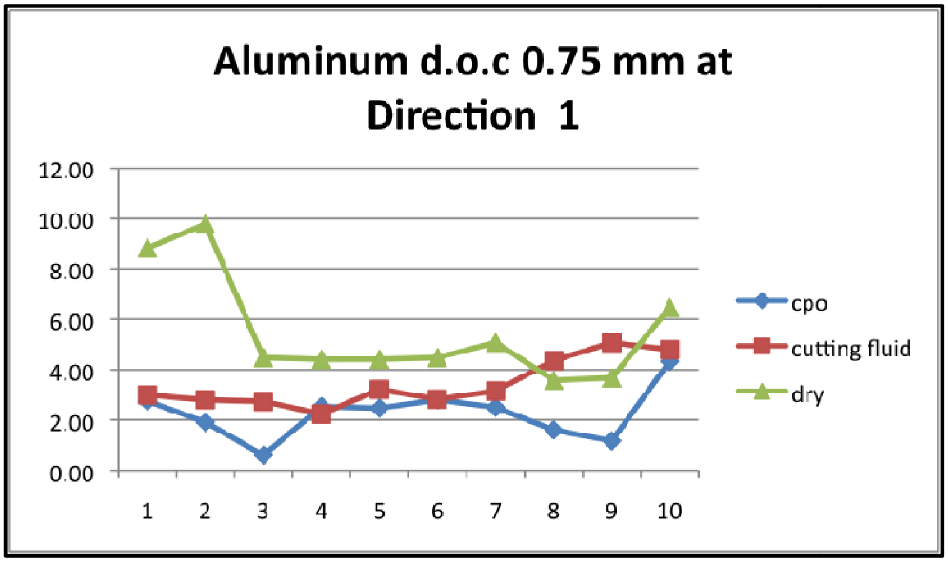


Figure 22: Surface roughness for Aluminum with 0.75 mm depth of cut at Direction 1

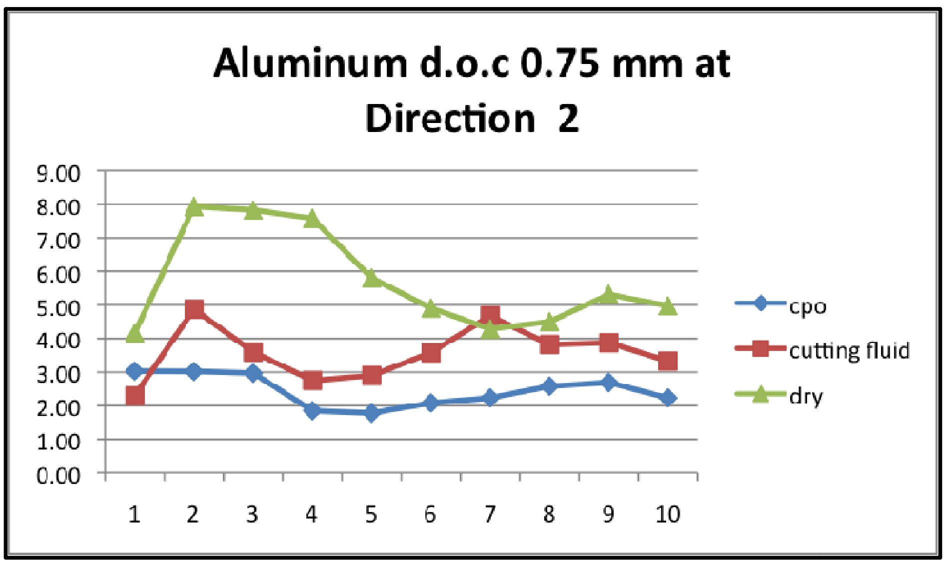


Figure 23: Surface roughness for Aluminum with 0.75 mm depth of cut at Direction 2

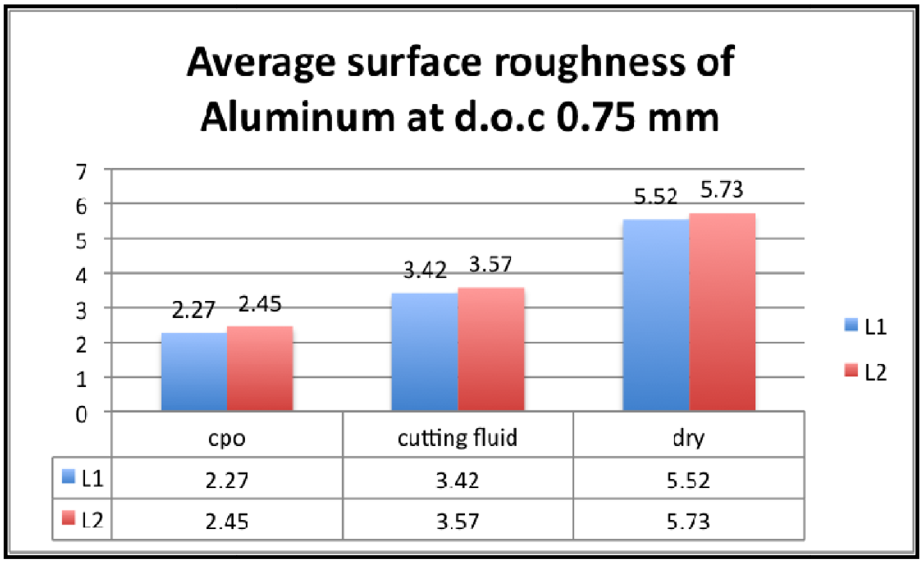


Figure 24: Average surface roughness for Aluminum with 0.75 mm depth of cut

Table 15: Data of surface roughness of Aluminum with depth of cut of 1.0 mm

Metal	Direction	Surface roughness using CPO as cutting fluid										Surface roughness using Solkut as cutting fluid										Surface roughness of dry machining									
		1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Aluminum	D1	1.47	1.53	1.30	1.44	1.62	1.60	1.62	1.67	1.61	1.68	2.45	2.45	1.93	2.05	2.40	1.99	2.07	1.99	1.99	2.28	3.28	4.50	4.07	3.27	3.31	3.49	3.35	4.46	4.02	3.36
	D2	2.71	2.04	0.71	2.13	2.73	2.73	2.23	2.75	1.03	1.53	2.66	3.42	3.27	2.57	3.01	4.22	2.99	3.51	1.94	2.28	5.41	4.73	3.49	5.37	8.21	6.91	7.03	8.82	4.94	8.01

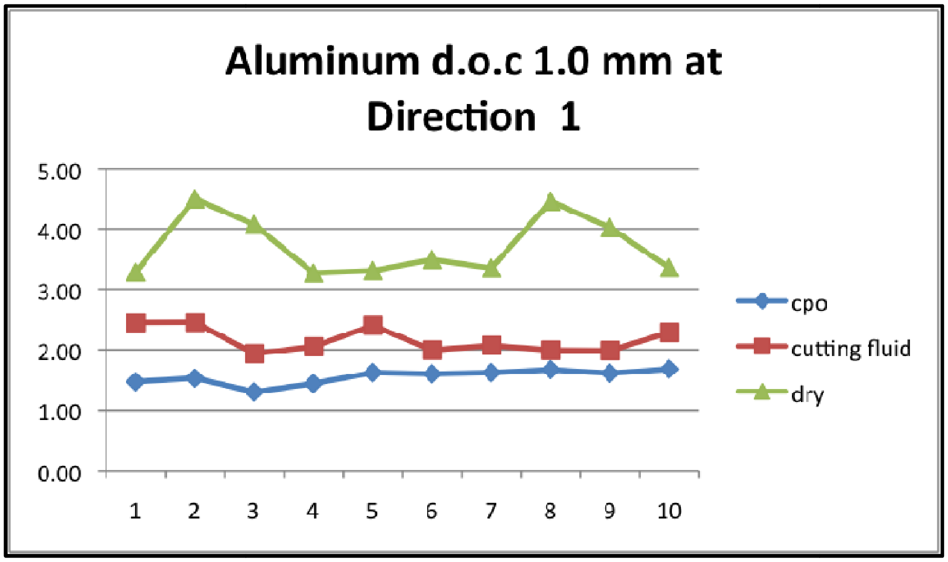


Figure 25: Surface roughness for Aluminum with 1.0 mm depth of cut at Direction 1

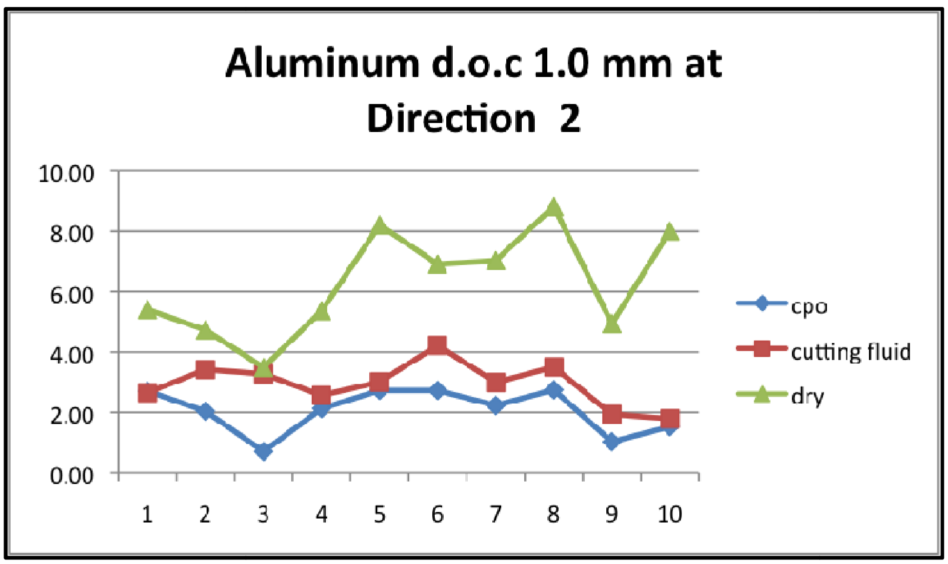
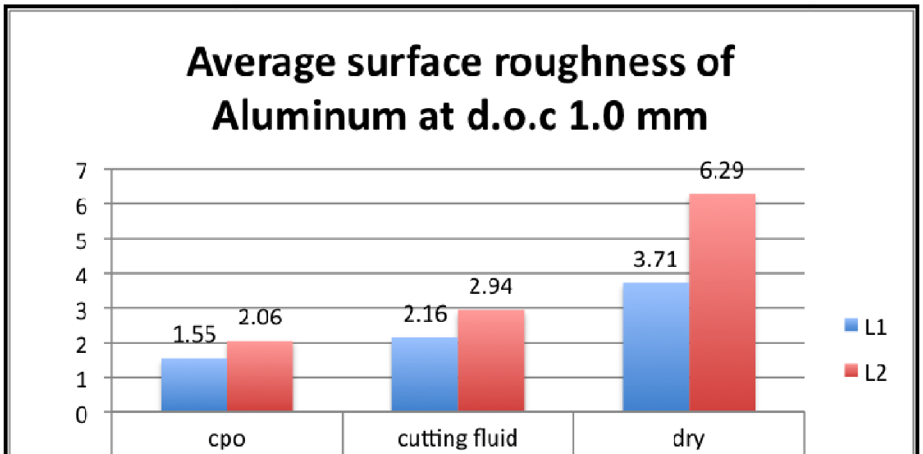


Figure 26: Surface roughness for Aluminum with 1.0 mm depth of cut at Direction 2



	cpo	cutting fluid	dry
L1	1.55	2.16	3.71
L2	2.06	2.94	6.29

Figure 27: Average surface roughness for Aluminum with 1.0 mm depth of cut

The discussion starts with the results of surface roughness of stainless steel that had been milling with depth of cut of 0.5 mm. Based on the readings that had been acquired from the measurement of surface roughness, the average reading at direction 1 is slightly lower than the average at direction 2. This result is highly expected as the author has initially set up the direction of the measurement to be in line with the cutting direction for direction 1 and perpendicular to the cutting direction for direction 2. In fact, these measuring direction are applicable throughout the surface roughness measurement for each sample.

From **Figure 7**, at direction 1, we can see that milling using CPO as cutting fluid produced an uneven pattern throughout the 10 readings with the highest value of surface roughness is at 5.97 µm and the lowest value is at 0.58 µm while having the average value of 3.84 µm.

At direction 2 from **Figure 8**, where the line of measurement is perpendicular to the axis of cutting, the surface roughness measurements of stainless steel machined using CPO as cutting fluid actually gives a rather consistent pattern albeit a slightly high value with the highest value of surface roughness is at 6.72 µm and the lowest value is at 5.92 µm while having the average reading of 6.49 µm.

As a further matter, the readings for milling using the conventional cutting fluid, *Solkut* at direction 1 show a consistent pattern of small readings throughout its 10 points of measurements with the highest value of surface roughness is at 2.93 µm and the lowest value is at 0.91 µm while its average reading is 1.49 µm. In addition, at direction 2 the result shows low values of surface roughness throughout its 10 point of readings even though there is a large value at one point with the highest value of surface roughness is at 8.47 µm and the lowest value is at 0.73 µm while having the average value of 2.39 µm.

Furthermore, the machining using dry cutting at direction 1 produced quite a high value of surface roughness throughout the 10 points of measurements with the highest value of surface roughness is at 7.24 µm and the lowest value is at 2.56 µm while its average reading is at 4.01 µm. While for dry machining at direction 2, throughout its 10 points of measurements with the highest value of surface roughness at 9.44 µm and the lowest value at 1.93 µm and having an average reading of 5.89 µm, the readings gathered of its surface roughness are consistently large for each point.

The second part of the discussion is on the surface roughness of stainless steel that had been machined with 0.75 mm depth of cut. As we can see from the graph, at direction 1 the data for surface roughness of workpiece machined using CPO with the highest value of surface roughness is at 5.97 µm and the lowest value at 0.58 µm with the average reading of 3.84 µm show quite a similar pattern to the data for the workpiece machined using CPO with 0.5 mm depth of cut at direction 1. And at direction 2, the highest value of surface roughness is at 6.72 µm and the lowest value at 5.92 µm with the average surface roughness value of 6.49 µm.

For the stainless steel machined using Solkut as the cutting fluid, at direction 1 the readings shows that the highest value of surface roughness is at 3.70 µm and the lowest value at 1.13 µm with the average value of 1.83 µm while at direction 2 the highest value of surface roughness is at 3.30 µm and the lowest value at 1.14 µm with the average reading of 2.38 µm.

Workpiece machined using dry machining still shows a very high value of surface roughness compared to the machining using CPO and conventional cutting fluid, Solkut. At direction 1, the data gathered are where the highest value of surface roughness is at 4.31 µm and the lowest is at 1.94 µm with the average reading of 2.97 µm. By the same token, at direction 2 we have the highest value of surface roughness to be at 4.46 µm and lowest at 2.53 µm while having the average reading of 3.14 µm.

The third part of the discussion focused on the surface roughness measurement of stainless steel machined with the depth of cut of 1.0 mm. For stainless steel machined using CPO as the cutting fluid, at direction 1 the workpiece shows the highest surface roughness value of 5.97 µm and the lowest value of 0.58 µm with the average roughness value of 3.84 µm. On the same sample at direction 2, the readings gathered are highest at 6.72 µm while lowest at 5.92 µm with the average value of 6.49 µm.

With the use of cutting fluid, Solkut during machining, at direction 1 the workpiece give out the reading of the highest at 6.07 µm and lowest at 1.41 µm while having the average reading of 2.25 µm. In addition at direction 2, the highest value of surface roughness recorded was at 7.90 µm with the lowest value at 1.29 µm while having the average value of 2.69 µm.

For the result of the surface roughness of workpiece machined using dry cutting at direction 1, the highest value was gathered at 6.44 µm and lowest at1.80 µm while having the average reading at 3.63 µm. Furthermore at direction 2, the highest surface roughness value was at 6.81 µm and the lowest value is at 1.71 µm with the average of 4.52 µm.

The fourth part of the discussion is on the surface roughness measurement of aluminum machined with the depth of cut of 0.5 mm using CPO as the cutting fluid. At direction 1 the highest value of surface roughness gathered is 3.15 µm while the lowest value is at 2.43 µm with the average of 2.68 µm. On the same sample, at direction 2 its highest value is at 8.97 µm and the lowest surface roughness value is at 1.76 µm with the average of 4.58 µm.

In addition, the surface roughness of aluminum workpiece machine using the Solkut at direction 1 is highest at 4.36-µm value and lowest at 1.47 µm with the average value of 2.93 µm. At direction 2, the highest value gathered of the surface roughness is at 8.69 µm and lowest at 1.76 µm having the average of 4.29 µm.

Furthermore for the workpiece undergo dry machining at direction 1, the highest measurement of surface roughness is at 3.87 µm and lowest at 1.29 µm with the average of 2.32 µm. At direction 2, the highest surface roughness measured is at 8.85 µm and the lowest value is at 1.61 µm with the average value of 3.82 µm.

The fifth part of the discussion is where the aluminum workpiece is machined using milling with the depth of cut of 0.75 mm. for aluminum machined with CPO as the cutting fluid, at direction 1 the highest surface roughness value measured was 4.33 µm and the lowest value measured was at 0.60 µm with having the average value of 2.27 µm. At direction 2, the highest value was at 3.03 µm and lowest at 1.78 µm with the average of surface roughness value at 2.45 µm.

Additionally, for aluminum machined using Solkut as the cutting fluid of choice, at direction 1 the highest surface roughness value measured is at 5.07 µm while the lowest value is measured at 2.24 µm with the average value of 3.42 µm. At direction 2, the highest data gathered of the surface roughness is at 4.88 µm and the lowest data is at 2.29 µm with the average value of 3.57 µm.

Moreover, for aluminum machined by dry cutting, the highest surface roughness value measured at direction 1 is at 9.78 µm while the lowest value is at 3.58 µm with the average value measured at 5.52 µm. At direction 2 the highest surface roughness value is at 7.93 µm and the lowest is at 4.16 µm with the average of 5.73 µm.

The sixth part of the discussion for this report is on the aluminum workpiece machined with the depth of cut of 1.0 mm. Workpiece machined with CPO as the cutting fluid give the highest value of surface roughness at direction 1 at 1.68 μm and the lowest value at 1.30 μm with the average surface roughness value of 1.55 μm. At direction 2 the highest roughness value measured is at 2.75 μm and the lowest at 0.71 μm with the average surface roughness value of 2.06 μm.

What's more, the workpiece shows a data where the highest value of surface roughness at direction 1 is at 2.45 μm and lowest value at 1.93 μm with the average value of 2.16 μm when machined using Solkut as the cutting fluid. At direction 2 the readings are that it is highest at 4.22 μm and lowest at 1.79 μm with the average surface roughness of 2.94 μm.

Over and above that, at direction 1 where the aluminum workpiece are machined using dry cutting, it shows the highest surface roughness value of 4.50 μm while having the lowest value at 3.27 μm with the average of 3.71 μm. At direction 2, the highest surface roughness value measured was at 8.82 μm and lowest at 3.49 μm with the average value of 6.29 μm.

From the results above, it was shown that both materials; stainless steel and aluminum that are machined using Solkut as the cutting fluid give a generally good surface roughness measurements. This result is already being expected from the start of the measurement since the application of the conventional cutting fluid are already established throughout the machining operation everywhere. This result also prove that the use of CPO as cutting fluid is still unstable in its application and thus its effect of cooling and providing lubrication in the machining are still unreliable.

The machining using the conventional cutting fluid give smaller values of surface roughness, R_a than the dry machining. These result shows that dry machining prove to be uneffective, at least in this milling operation due to many factors including the tool used was not specifically build to be used in dry machining. A tremendous amount of heat and friction is generated as a cutting tool drives into a workpiece. STLE-member Dr. Emmanuel Ezugwu with The School of Engineering System & Design at London's South Bank University, reports that 70% of the heat generated in machining originates with plastic deformation of the workpiece. The remaining 30% of the heat arises from friction at the chip/tool and tool/workpiece interfaces. Without metalworking fluid, excessive tool wear and inferior surface finish may occur during machining [2].

It is evident that as the values of depth of cut is increased the surface roughness become better which is expected. This in combination with the use of the conventional cutting fluid, Solkut and CPO gives a very good surface quality compared to dry machining although there are some exceptions, which might be caused from a small error during the machining and also during the maesurement.

The operation of dry cutting of aluminum has been impractical and in a way give a small error due to the build-up of hot aluminum on tools in the absence of the cooling effects and lubrication provided by cutting fluids.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

By conducting this research project, one is able to analyze the experimental results of milling machining using CPO, conventional cutting fluid, Solkut as a cutting fluid and also dry machining.

Comparing the surface roughness on two different materials: aluminum and stainless steel machine by milling machining using CPO, Solkut and dry machining, the result are concluded as below:

1. Surface roughness of stainless steel and aluminum materials machined using milling machining.
    - A higher value of average roughness, e.g. R_a (6.49µm) was observed on the stainless steel compared to aluminum R_a (4.58µm) in the machining using CPO as the cutting fluid.
    - Stainless steel machined using Solkut as the cutting fluid show a small value of average surface roughness R_a (2.96µm) compared to CPO R_a (6.49µm) and dry machining R_a (5.89µm), as been expected.
    - Aluminum machined using Solkut as the cutting fluid show a small value of average surface roughness R_a (4.29µm) compared to CPO R_a (4.58µm) and dry machining R_a (6.29µm), as been expected.
    - Aluminum material is not suitable to be machined with dry cutting condition without applying the proper cutting fluid as shown from the result of this study.

Based on the result gathered on the milling machining of stainless steel and aluminum materials using CPO and Solkut as the cutting fluid, and also dry cutting, it could be concluded that crude palm oil CPO need further improvements before it can be commercialized as a cutting fluid in machining. It does in fact show a very promising prospect as a suitable alternative cutting fluid.

5.2 Recommendations

Based on the experiences gained during conducting of this project a few recommendations are as follows:

5.2.1 Future studies

A lot more improvement needed to be done to increase the performance and properties of the CPO as a cutting fluid. Further study has to be done on the right additives added to the CPO to make it suitable to function as a cutting fluid in machining operations.

5.2.2 Facilities improvements

As an earlier planned this study should include the effect of cutting forces on CPO as a cutting fluid using cutting force measurement technique. However, because of the problem with the equipment measuring devise the cutting force measurement cannot be conducted until the end of this project. Therefore, it is suggested that a better facility in terms of the availability of the equipment in the lab to provide the students a ready to use equipments in order to conduct their experiments, to be looked after seriously.

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